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Some Factors Which Influence The Survival of Hatchery Atlantic Salmon (Salmo salar) Smolts Utilized for Enhancement Purposes

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ABSTRACT

Farmer, G.J. 1992. Some factors which influence the survival of hatchery Atlantic salmon (Salmo salar) smolts utilized for enhancement purposes. Can. Tech. Rep. Fish. Aquat. Sci. No. 1855. 19 p.

Sixty-nine groups of 2+ Atlantic salmon smolts and 27 groups of 1+ smolts produced at the Mactaquac FCS have been marked with modified Carlin tags and released in the Saint John River, N.B., during the 1973-1988 period. During the same period, 35 groups of tagged 1+ smolts produced at the Mersey FCS were released in the LaHave River, N.S. The numbers of tagged adult salmon that were subsequently recovered in distant and local commercial fisheries, in Native food fisheries, by anglers and at collection facilities operated by the Department of Fisheries and Oceans provided a measure of the survival rate of the various smolt groups. Neither release date nor river discharge at time of release significantly influenced the survival of tagged smolts. Survival rates for groups of smolts released in the LaHave River fluctuated from year to year in a pattern similar to that observed for groups of smolts released in the Saint John River. The year-to-year fluctuation in the survival of the LaHave and Saint John smolts was correlated and considered to reflect changing conditions at sea. Stepwise multiple regression analysis indicated that 44-68% of the variation in the survival rate of the 1+ and 2+ smolts was attributable to smolt weight at time of release, smolt quality as determined by an index and to sea conditions during a particular year. The results of the analysis provide rationale for modifying hatchery rearing practices and facilities to increase mean smolt weight and to improve smolt quality.

Key words: Atlantic salmon smolts, enhancement, survival rate, release date, river discharge, smolt weight, smolt quality, sea conditions.

RÉSUMÉ

Farmer, G.J. 1992. Some factors which influence the survival of hatchery Atlantic salmon (Salmo salar) smolts utilized for enhancement purposes. Can. Tech. Rep. Fish. Aquat. Sci. No. 1855. 19 p.

De 1973 à 1988, on a doté des groupes de saumoneaux de l'Atlantique, soit soixante-neuf groupes d'âge 2+ et 27 groupes d'âge 1+, produits à la Station piscicole de Mactaquac, d'étiquettes Carling modifiées et on les a relâchés dans le fleuve Saint-Jean (N.-B.). Au cours de la même période, on a mis à l'eau dans la rivière LaHave (N.-É.) 35 groupes de saumoneaux étiquetés d'âge 1+ produits à la Station piscicole de Mersey. Le nombre d'adultes étiquetés qui ont été subséquemment recapturés, que ce soit par des pêcheurs locaux, dans des endroits éloignés, dans le cadre de la pêche de subsistance des autochtones, par des pêcheurs à la ligne, ou à des installations de collecte du ministère des Pêches et des Océans, nous a fourni une mesure du taux de survie des groupes de saumoneaux. Ni la date de mise à l'eau, ni le débit de la rivière n'ont eu d'influence notable sur le taux de survie des saumoneaux étiquetés. Dans le cas des saumoneaux libérés dans la rivière LaHave, ce taux a suivi d'année en année des fluctuations comparables à celles des groupes de saumoneaux relâchés dans le fleuve Saint-Jean. On a établi une corrélation entre ces fluctuations et déterminé qu'elles reflétaient des changements de conditions en mer. Une analyse de régression multiple séquentielle a révélé que l'écart entre les taux de survie des saumoneaux de 1+ et de 2+ était, dans une proportion de 44 à 68 p. 100, imputable au poids des saumoneaux lors de leur mise à l'eau, à la qualité de ces saumoneaux (déterminée d'après un indice) et aux conditions en mer durant une année donnée. Les résultats de l'analyse militent en faveur de la modification des méthodes et des installations d'élevage en écloserie en vue d'accroître le poids et la qualité des saumoneaux.

INTRODUCTION

The Saint John River is one of the largest North American rivers draining to the Atlantic Ocean. The drainage area of 54,930 km^2 is comprised of a portion of northern Maine in the United States and adjacent areas of Quebec and New Brunswick in Canada. The river has a length of 676 km and elevation declines 481 m from the source to head-of-tide (Ruggles and Watt 1975). Most of the available head of the Saint John River is now utilized for hydroelectric purposes.

The largest and most recently constructed hydroelectric dam on the Saint John River was completed in 1968 at Mactaquac located 3 km above the head-of-tide. The project not only created a reservoir 97 km in length, resulting in the loss of a significant area of salmon habitat, but had the potential to eliminate populations of fish that migrate to areas of the river located above the dam. Thus, fish collection facilities were incorporated in the dam and a fish culture station for rearing juvenile Atlantic salmon was constructed 2.5 km downstream to compensate for losses in salmon production.

The Mactaquac Fish Culture Station (FCS) produced about 350,000 two-year-old (2+) Atlantic salmon smolts when it was completed in 1968. During 1983/84, an Accelerated Rearing Facility was constructed to utilize the warm waste water from the generating units at the Mactaquac Generating Station (Farmer et al. 1990). The development of eyed eggs and alevins is accelerated by use of the warm water so that feeding begins during April, two months earlier than had been possible in the past. Parr are reared in the warm waste water for two months and then transferred, during June, to the Mactaquac FCS where they are reared for an additional 11 months. Production at the station is now 300,000 one-year-old (1+) salmon smolts.

The release of 244,000 2+ smolts in the Saint John River during 1979 provided a return to the river of 10,793 one-sea-year (1SY) and 2612 multi-sea-year (MSY) salmon (Marshall 1990). The return of hatchery adult salmon to the river has since declined; the release of 113,000 1+ smolts in 1987 provided a return to the river of only 1193 adults. The decline in the return of hatchery adults coincided with a reduction in the number of hatchery smolts released from the Mactaquac FCS during the 1980's and with the production of 1+ rather than 2+ smolts. The aim of the present study is to review available information on the recovery of tagged adult salmon to determine which factors influence the survival of hatchery-reared smolts. Identification of the factors which influence smolt survival provides rationale for modifying hatchery rearing practices and facilities and smolt release strategies.

METHODS AND MATERIALS

Sixty-nine groups of 2+ smolts and 27 groups of 1+ smolts have been marked with modified Carlin tags (Eisner and Ritter 1979) and released from the Mactaquac FCS to the Saint John River, N.B., during the 1973-1988 period. The numbers of tagged adult salmon subsequently captured in distant and local commercial fisheries, by natives and anglers in the Saint John River and at collection facilities incorporated in the Mactaquac Dam located near the Mactaquac FCS are listed in Newbould (1987; 1990). In total, 340,673 tagged 1+ and 2+ smolts have been released from the Mactaquac FCS to the Saint John River during the 1973-1988 period and 6782 tagged adult salmon recovered.

Thirty-five groups of 1+ smolts marked with Carlin tags were transported from the Mersey FCS during the 1976-1988 period and released in the LaHave River, N.S., above Morgan Falls. In total, 118,107 smolts were released and 1568 tagged adult salmon were subsequently recaptured in distant and local commercial fisheries, in the LaHave recreational fishery and at the Morgan Falls fishway (Newbould 1990).

The numbers of recaptured adult salmon are indicative of the survival rates of the various groups of tagged smolts. The recovery of tagged adult salmon reported in this study provides minimal estimates of smolt survival because corrections are not applied to account for tag loss, differential mortality attributable to the tag or for the non-reporting of tagged adult salmon captured in commercial and recreational fisheries.

For most groups of tagged smolts released into the LaHave and Saint John rivers, information exists on release date, river discharge at time of release (Environment Canada 1973-1988), mean smolt weight and on the percentage of good quality smolts. Smolt quality is determined each year during April or May a few weeks prior to release. Fifty to 100 smolts within each group are examined for fork length, weight, condition factor (weight/length^3 · 100), incidence and magnitude of fin rot and erosion, and incidence of physical abnormalities such as cataracts, blindness or spinal curvatures. The percentage of good quality smolts within each group is estimated from these variables and the results are presented in an annual report (for example, McLean 1990). Smolts selected for tagging are greater than 14 cm (30 g) and are not considered to be of poor quality because they do not satisfy the minimum fork length standard specified in the quality evaluation. Quality evaluation of the groups of tagged smolts therefore provides a measure of the incidence and magnitude of fin rot and erosion and to a lesser extent of various physical abnormalities.

The number of tagged adults recovered from each smolt group is expressed as a percentage of the number of smolts released, and the percentage transformed by use of the $\sqrt{\%} + .5$ transformation (Steel and Torrie 1960). Relationships between the recovery of tagged adult salmon and smolt release date (day of year), river discharge at time of release (m^3/s), mean smolt weight (g) and percentage of good-quality smolts were examined for significance by linear regression analysis. The percentage of good-quality smolts within each group was transformed by use of the $\sqrt{100 - \%\ good\ quality}$ transformation (Steel and Torrie 1960) prior to statistical analysis. The survival rate of hatchery and wild smolts fluctuates from year to year in a similar pattern and is thought to be influenced by conditions at sea (Reddin 1986; Ritter 1989). The survival rate of hatchery smolts released in the LaHave River should therefore be correlated with the survival of hatchery smolts released in the Saint John River during the same year. This relationship was examined in an attempt to quantify that portion of the year-to-year variation in hatchery smolt survival attributable to varying sea conditions. The relationship between the dependent variable ($\sqrt{\%\ recovery} + .5$) and the significant independent variables was then examined by stepwise multiple regression analysis. The objective of this study is to determine which variables are of importance in determining the survival of hatchery-reared smolts to provide rationale for modifying hatchery rearing practices and facilities and altering smolt release strategies.

RESULTS

RETURN OF HATCHERY ADULT SALMON TO THE SAINT JOHN RIVER

The number of hatchery smolts (tagged + untagged) released each year in the Saint John River declined from 337,280 in 1974 to 89,050 in 1985 (Marshall 1990)(Fig. 1A). Thereafter, the number of smolts released increased to 238,200 by 1989. Most smolts released during the 1974-1984 period were 2+, whereas all smolts released since 1985 have been 1+. The return of hatchery, adult salmon to the Saint John River from the release of different smolt year-classes during the 1974-1980 period exceeded 6000 adults yearly (except for the adult return from the 1977 smolts) and reached maxima of 11,799 and 13,405 adults (Marshall 1990). The return of adults to the river from smolts released during the 1981-1988 period declined reflecting, in part, the reduced numbers of smolts which were released. Adult returns from the smolt year-classes released during that period ranged from 1193 to 4024.

SIZE AND QUALITY OF THE TAGGED SAINT JOHN SMOLTS

Both the mean weight and quality of the tagged 2+ smolts released from the Mactaquac FCS during the 1974-1984 period showed a gradual decline (Fig. 1B). For example, 2+ smolts released during 1975 weighed 132 g and 93% were considered to be of good quality; whereas 2+ smolts released during 1982 weighed 82 g and only 60% were of good quality. One-year-old smolts have been released from the Mactaquac FCS since 1985, when tagged smolts weighed 62 g and 89% were of good quality. Mean weight of the tagged 1+ smolts has increased since 1985 and was 81 g during 1988. Changes in the size and quality of the tagged smolts released from the Mactaquac FCS during the 1974-1988 period can be expected to reflect changes in the size and quality of the untagged smolts released during that period.

FACTORS WHICH INFLUENCED THE SURVIVAL OF TAGGED 1+ SAINT JOHN SMOLTS

Groups of tagged 1+ smolts were released in the Saint John River from day 117 to day 139 during the years 1976-1988. There was not a significant linear relationship between the recovery of tagged adult salmon ($\sqrt{\%} + .5$) and smolt release date expressed as day of the year (Df 1 and 25; $R^2 = .064$; $P > .05$; Fig. 2B). Similarly, there was not a significant linear relationship between the recovery of tagged adults and river discharge (m^3/s) at time of smolt release (Df 1 and 25; $R^2 = .017$; $P > .05$; Fig. 2A).

The recovery of tagged adult salmon ($\sqrt{\%} + .5$) was observed to increase with increases in mean weight (g) of the groups of 1+ smolts released from the Mactaquac FCS (Fig. 4A). The linear relationship between these variables is significant (Df 1 and 20; $R^2 = .328$; $P < .01$) and described by the equation:

$$\sqrt{\%} + .5 = 0.7384 + 0.0080 \text{ smolt weight}$$

The recovery of tagged adult salmon ($\sqrt{\%} + .5$) also increased with increases in the percentage of good quality tagged 1+ smolts released from the Mactaquac FCS (Fig. 4B). The linear relationship between these variables is significant (Df 1 and 19; $R^2 = .473$; $P < .01$) and described by the equation:

$$\sqrt{\%} + .5 = 1.5295 - 0.0801 \sqrt{100 - \% \textit{ good quality}}$$

Recoveries of tagged LaHave and Saint John adult salmon have fluctuated from year to year in a similar pattern (Fig. 3). There is a significant linear relationship between the recovery of tagged Saint John adults and tagged LaHave adults, which results from the release of 1+ smolts during the same year (Df 1 and 19; $R^2 = .348$; $P < .01$). The relationship is described by the equation:

$$\sqrt{\textit{Saint John recovery}, \% + .5} = 0.5622 + 0.4702 \sqrt{\textit{LaHave recovery}, \% + .5}$$

The recovery rate of tagged Saint John adult salmon was thus observed to be influenced by smolt weight and quality, as well as by the recovery of LaHave adults resulting from release of the same smolt year-class. The latter variable was introduced to explain some of the year-to-year variation in smolt survival which we attribute to sea conditions. The influence of these independent variables, as well as the smolt weight x % good quality interaction on the dependent variable, the recovery of tagged Saint John adults ($\sqrt{\%} + .5$), was examined by stepwise multiple regression analysis:

Independent variable	Coefficient	R^2 change	T-value	P
$\sqrt{100 - \%\ good\ quality}$	-.1078	.473	-4.532	<.01
$\sqrt{LaHave\ recovery,\ \% + .5}$	.2527	.081	2.254	<.05
smolt weight x $\sqrt{100 - \%\ good\ quality}$	.9124E-3	.175	2.291	<.05
intercept	1.1029			

Adjusted R^2 = .681; Df = 3 and 17; F = 15.25; standard error of estimate = .1244

The regression analysis indicates that 68% of the variation in the recovery rate of tagged Saint John adults can be explained by smolt quality, the smolt weight x quality interaction and by the recovery of tagged LaHave adults. The smolt quality variable accounted for most of the explained variation in adult recovery.

FACTORS WHICH INFLUENCED THE SURVIVAL OF TAGGED 2+ SAINT JOHN SMOLTS

Discharge of the Saint John River at time of smolt release varied from 1060-10,565 m^3/s during the 1973-1984 period. However, there was not a significant linear relationship between the recovery of tagged Saint John adult salmon ($\sqrt{\%} + .5$) and river discharge at time of 2+ smolt release (Df 1 and 67; R^2 = .020; P > .05; Fig. 2A).

Groups of tagged 2+ Saint John smolts were released as early as day 113 and as late as day 149 during the 1973-1984 period. There was not a significant linear relationship between the recovery of tagged adults ($\sqrt{\%} + .5$) and smolt release date (day of the year) (Df 1 and 67; R^2 = .030; P > .05; Fig. 2B).

The recovery of tagged Saint John adults ($\sqrt{\%} + .5$) was observed to increase with increases in the mean weight (g) of the 2+ smolts released from the Mactaquac FCS (Fig. 4A). The linear relationship between these variables was significant (Df 1 and 42; R^2 = .110; P < .05) and described by the equation:

$$\sqrt{\%} + .5 = 0.8120 + 0.0072 \text{ smolt weight}$$

Adult recovery ($\sqrt{\%} + .5$) also increased with increases in the quality of the 2+ smolts which were released from the Mactaquac FCS (Fig. 4B). The linear relationship between these variables was significant (Df 1 and 42; R^2 = .128; P < .05) and described by the equation:

$$\sqrt{\%} + .5 = 2.0089 - 0.0945 \sqrt{100 - \%\ good\ quality}$$

The recovery of Saint John adult salmon from the release of tagged 2+ smolts at Mactaquac was correlated with the recovery of tagged LaHave adults from the release of 1+ smolts in the LaHave River the same year (Fig. 3). The relationship between these variables was significant (Df 1 and 27; R^2= .394; P < .01) and described by the equation:

$$\sqrt{\text{Saint John recovery, \% + .5}} = 0.6024 + 0.7819\ \sqrt{\text{LaHave recovery, \% + .5}}$$

The influence of the significant independent variables, as well as the smolt weight x % good quality interaction, on the recovery of tagged Saint John adults ($\sqrt{\%+.5}$) was examined by stepwise multiple regression analysis:

Independent variable	Coefficient	R^2 change	T-value	P
$\sqrt{\text{LaHave recovery, \% + .5}}$	.8996	.395	4.856	<.01
$\sqrt{100 - \%\ \text{good quality}}$	-.9603E-1	.085	-2.057	<.05
intercept	.9220			

Adjusted R^2 = .439; Df = 2 and 26; F = 11.97; standard error of estimate = .2901.

The only significant independent variables observed to influence the recovery of tagged Saint John adults were the recovery of LaHave adults (represents sea conditions) and the quality of the 2+ smolts released from the Mactaquac FCS.

FACTORS WHICH INFLUENCED THE SURVIVAL OF TAGGED 1+ LAHAVE SMOLTS

Tagged 1+ smolts have been released in the LaHave River above Morgan Falls as early as day 113 and as late as day 155 during the 1976-1988 period. There was not a significant linear relationship between smolt release date and the subsequent recovery of tagged LaHave adults (Df 1 and 33; R^2 = .017; P > .05). River discharge at time of smolt release has varied from 12.4 - 107.3 m^3/s during the 1976-1988 period. However, there was not a significant linear relationship between discharge of the LaHave River at time of release and the subsequent recovery of tagged LaHave adults (Df 1 and 33; R^2 = .028; P > .05).

Mean weight of the 35 groups of tagged 1+ smolts released in the LaHave River during the 1976-1988 period ranged from 39.7-65.7 g. The recovery of tagged LaHave adults ($\sqrt{\%+.5}$) was observed to increase with increases in mean smolt weight (g) (Fig. 5A). This relationship was significant (Df 1 and 33; R^2 = .156; P < .05) and described by the equation:

$$\sqrt{\%+.5} = 0.6129 + 0.0157\ \text{smolt weight}$$

The recovery of tagged LaHave adults ($\sqrt{\%+.5}$) also increased with increases in the quality of the 1+ smolts which were released in the LaHave River (Fig. 5B). The linear relationship between these variables was significant (Df 1 and 33; R^2 = .151; P < .05) and described by the equation:

$$\sqrt{\%+.5} = 1.5911 - 0.0655\ \sqrt{100 - \%\ \text{good quality}}$$

The relationship between the recovery of tagged LaHave adults and tagged Saint John adults resulting from smolts released the same year was significant (Df 1 and 33; R^2 = .119; P < .05) and described by the equation:

$$\sqrt{\text{LaHave recovery, \% + .5}} = 0.9040 + 0.3169\ \sqrt{\text{Saint John recovery, \% + .5}}$$

The influence of the significant independent variables, as well as the smolt weight x % good quality interaction, on the recovery of tagged LaHave

adults ($\sqrt{\% + .5}$) was examined by stepwise multiple regression analysis:

Independent variable	Coefficient	R^2 change	T-value	P
smolt weight	.2363E-1	.156	4.869	<.01
smolt weight x $\sqrt{100 - \%\ good\ quality}$	-.1943E-2	.160	-4.775	<.01
$\sqrt{Saint\ John\ recovery,\ \% + .5}$	.5071	.270	4.495	<.01
intercept	-.2433			

Adjusted R^2 = .546; Df 3 and 31; F = 14.63; standard error of estimate = .1978

Smolt weight, the smolt weight x quality interaction and the recovery of Saint John adults (sea conditions) explained 54.6% of the variation in the recovery of tagged LaHave adults.

INFLUENCE OF WATER DEPTH ON SMOLT SIZE AND QUALITY

Salmon have been reared at the Mactaquac FCS in 7.6 or 11 m Swedish-type ponds which operate with a 50 cm depth of water. Some of the ponds have been modified to operate with a 100 cm depth of water in an attempt to reduce the incidence of fin rot and erosion observed among 1+ smolts reared in shallow ponds. Fin quality of 1+ smolts reared in shallow ponds at the Mactaquac FCS is generally acceptable until the February-April period when fin rot appears on a proportion of the smolts. One-year-old smolts reared at the station in either deep or shallow ponds were evaluated during April 1990 and the results of the evaluation reported in McLean (1990). Medium grade smolts (grading occurred the previous September-October) reared in deep ponds were larger and had a lower incidence of fin rot and erosion than did medium grade smolts reared in shallow ponds (Table 1). Similarly, large grade smolts reared in deep ponds were not only heavier (mean 92.7 g) than large grade smolts reared in shallow ponds (mean 67.1 g), but the incidence of fin rot and erosion was lower among smolts in the deep ponds. For example, only 6.0% of the large grade smolts reared in deep ponds were found to be of poor quality because of excessive fin rot and erosion, whereas 24.5% of those in the shallow ponds were poor because of excessive fin rot and erosion. The evaluation indicates that 94% of the large grade smolts reared in deep ponds were of good quality, but that only 72.7% of those reared in shallow ponds were of good quality (Table 1).

Table 1. Comparison of smolts reared in deep and shallow ponds*

Pond type	Smolt grade	Number sampled	Density (kg/m^3)	Length (cm)	Weight (g)	% With poor fins	% Good quality
shallow	medium	400	5.0	14.6	39.0	12.8	64.5
deep	medium	250	3.3	15.1	43.4	1.2	86.4
shallow	large	1000	6.2	18.4	67.1	24.5	72.7
deep	large	100	4.4	20.1	92.7	6.0	94.0

*Mactaquac F.C.S., April, 1990.

DISCUSSION

The recovery rate for LaHave and Saint John adult salmon was not influenced by smolt release dates ranging from day 113 to day 155. Conversely, Ritter (1989) indicated that smolts passing through an estuary early or late during their migration period experience a lower survival rate. For example, the survival of 1+ smolts released in the LaHave River, N.S., during the 1978-1981 period was maximal when release date was near day 130 and minimal when smolts were released beyond day 150 (Ritter 1989). The use of tag recovery information derived from a greater number of smolt year-classes undoubtedly increases the variation, resulting in the lack of correlation between smolt release date and adult recovery. Despite this, the present analysis suggests that the release of smolts in the LaHave and Saint John rivers between day 113 and 150 of a particular year is within the range of release dates that results in maximal survival.

Atlantic salmon released as smolts are subjected to considerable mortality at the post-smolt stage (Thorpe 1980). In Norwegian estuaries and fjords, most of the mortality results from predation by different species of marine fish (Hvidsten and Møkkelgjerd 1987) and birds (Reitan et al. 1987). Hvidsten and Hansen (1988) demonstrated that the survival of hatchery smolts released in two Norwegian rivers increased with increased river discharge at time of release. Predation of the smolts was presumed to have been reduced at high river discharge. Discharge at time of smolt release explained from 30 to 42% of the variation in adult recovery rate (Hvidsten and Hansen 1988). Conversely, Reitan et al. (1987) observed a greater predation of smolts in a different Norwegian river by the common gull, Larus canus, when river discharge was high. In the lower part of the river, large areas are inundated by fresh water during high discharge and the smolts are more vulnerable to predation in these shallower areas. There was not a significant correlation between discharge of either the LaHave or Saint John rivers at the time of smolt release and the subsequent recovery rate of tagged adults. Attempts have been made to release smolts in the Saint John River during periods of high discharge to increase the subsequent recovery of adult salmon. Results of this analysis suggest that, while this practice does not result in a reduced rate of adult recovery, other factors are of more importance in determining post-smolt survival.

There was a linear increase in the recovery of adult salmon with increases in the mean weight of the 1+ smolts released in the LaHave River, and with increases in the mean weight of the 1+ and 2+ smolts released in the Saint John River. Mean smolt weight explained from 11 to 33% of the variation in adult recovery rate. Mean weight of the 1+ smolts released in the Saint John River explained more of the variation in adult recovery rate than did mean weight of the 2+ smolts released in that river. Mean weight of the 1+ smolts ranged from 32-81 g and weight of the 2+ smolts from 63-145 g. Other studies have demonstrated that there is a linear increase in adult recovery rate with increasing smolt length at release up to the 18-22 cm range (62-111 g) but that recovery rate does not always continue to increase when smolts exceed 18-22 cm (Peterson 1973; Larsson 1977; Ritter 1977). Adult recovery rates from the release of 1+ smolts will be less than from the release of 2+ smolts until mean weight of the 1+ smolts $\geq$ 62 g. Attempts are being made to increase the size of the 1+ smolts by the use of accelerated rearing programs, by grading and by modification of outdoor rearing ponds. During 1990, 1+ smolts produced at the Mactaquac FCS had a mean weight of 55 g and those produced at the Mersey FCS a mean weight of 39 g.

Ritter et al. (1986) demonstrated that larger hatchery smolts produce proportionately more 1SW salmon than MSW salmon. For example, only 6-36% of the adults produced by releasing 36-58 g 1+ smolts in the Saint John River

were 1SW; whereas from 46-85% of the adults produced by releasing 93-114 g 2+ smolts were 1SW (Ritter et al. 1986). The greater incidence of 1SW salmon which results from the release of larger smolts explains, in part, their greater survival; since natural mortality primarily acts for only one-sea-year rather than for two-sea-years. For enhancement programs such as those conducted on the LaHave and Saint John rivers, the increased recovery of adults which can be realized by releasing larger smolts must be considered in terms of the greater proportion of 1SW salmon which will result from this practice.

Increases in the percentage of good quality 1+ and 2+ smolts released in the LaHave and Saint John rivers increased the subsequent recovery of tagged, adult salmon. From 13 to 47% of the variation in adult recovery rate was explained by smolt quality. Smolts selected for tagging exceeded the minimum size requirements specified in the smolt quality index. Therefore, most tagged smolts considered to be of poor quality had an excessive amount of fin rot or erosion. The increased rate of adult recovery which accompanies smolt quality improvements is considered primarily attributable to improvements in fin condition.

The survival rate observed for different stocks of adult salmon has been observed to fluctuate from year to year in a similar pattern (Ritter 1989). Factors affecting survival can have widespread effects, as indicated by the low survival rates observed for the 1977 smolts originating in rivers from Maine to southern Labrador (Ritter 1989). The variable survival rate of post-smolt salmon cannot be controlled, is poorly understood, and may be attributed to factors such as predator abundance, sea-surface temperatures in the northwest Atlantic or to the scarcity of forage (Reddin 1986; Ritter 1989). The survival rate of tagged Saint John smolts was correlated with the survival rate of tagged LaHave smolts released the same year. This correlation was utilized in a multiple regression approach to quantify the year-to-year variation inherent in hatchery smolt survival and attributable to varying conditions at sea. The analysis indicated that 68% of the variation in the survival rate of tagged 1+ Saint John smolts can be explained by smolt quality, the smolt weight x quality interaction and by conditions at sea. Most of the variation in the survival of the tagged 1+ Saint John smolts was explained by smolt quality and the smolt weight x quality interaction. About 55% of the variation in the survival rate of the tagged 1+ LaHave smolts was explained by smolt weight, the smolt weight x quality interaction and by conditions at sea. This indicates that increases in the size of the 1+ smolts produced at the Mersey FCS, as well as further improvements in smolt quality, will result in increased rates of smolt survival. About 44% of the variation in the survival rate of the 2+ Saint John smolts was attributable to sea conditions and to smolt quality. Weight of the 2+ smolts was not a significant variable in the multiple regression analysis, probably because all groups of smolts had a mean weight > 62 g. It has been demonstrated that smolt survival may not always continue to increase with increases in smolt weight beyond 62 g (Peterson 1973; Larsson 1977; Ritter 1977).

Although we are unable to control some of the factors which influence the survival rate of hatchery smolts, survival can be enhanced by increasing mean smolt size at time of release and by improving smolt quality. A reduction in the incidence of fin rot and erosion among hatchery smolts will result in an increased rate of post-smolt survival. The decline in the return of hatchery adult salmon to the Saint John River during the 1980's was related to a reduction in the number of hatchery smolts released from the Mactaquac FCS during that decade and to reductions in mean smolt size and quality. Reductions in smolt size and quality were attributable to the sale of a significant proportion of the good quality smolts produced at the station during that period to the developing New Brunswick aquaculture industry and to conversion from a two-year smolt program to a one-year smolt program.

A number of rearing practices and facilities have been modified to increase the size and improve the quality of the 1+ smolts produced at the Mactaquac FCS. These include accelerated rearing by the use of heated water, grading, improvements in diets and water quality and modification of the rearing ponds. The production of 1+ smolts in deep ponds which operate with a water depth of 100 cm, rather than in shallower ponds which have a water depth of 50 cm, appears to be a method whereby smolt size can be increased and the incidence of fin rot and erosion reduced. The increase in size and improvement in fin condition which has been observed for smolts reared in deeper ponds may be related to a reduction in rearing density, current velocity and stress levels and possibly to greater food availability.

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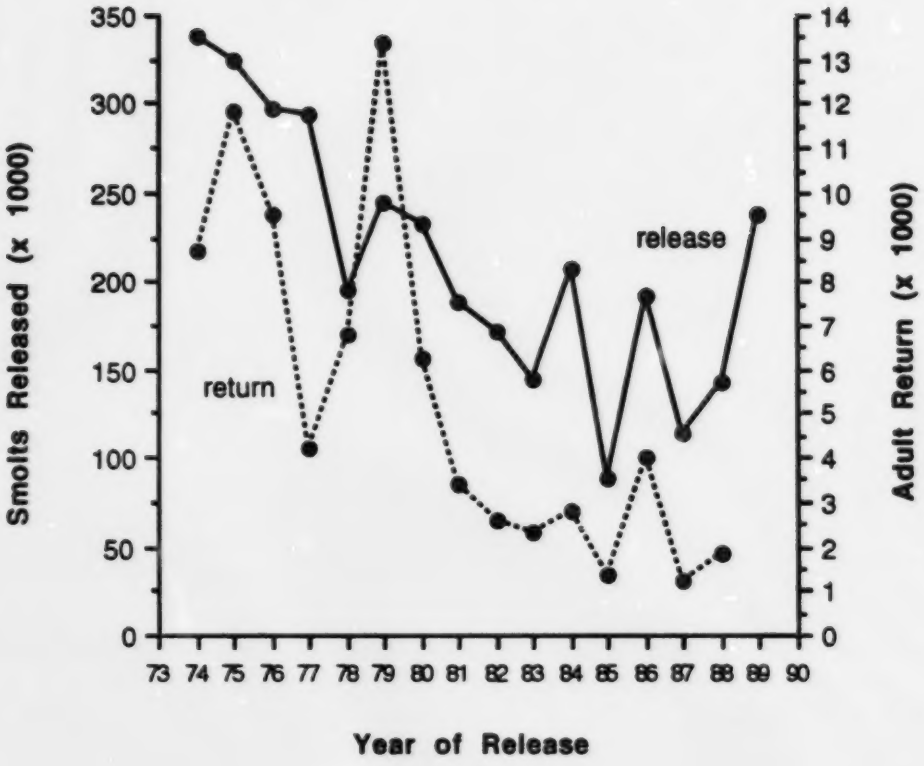

Figure 1A. Numbers of smolts released from the Mactaquac FCS to the Saint John River, N.B., during the 1974-1989 period and the corresponding return to the river of hatchery adult salmon (total includes 1SY and MSY salmon; from Marshall 1990).

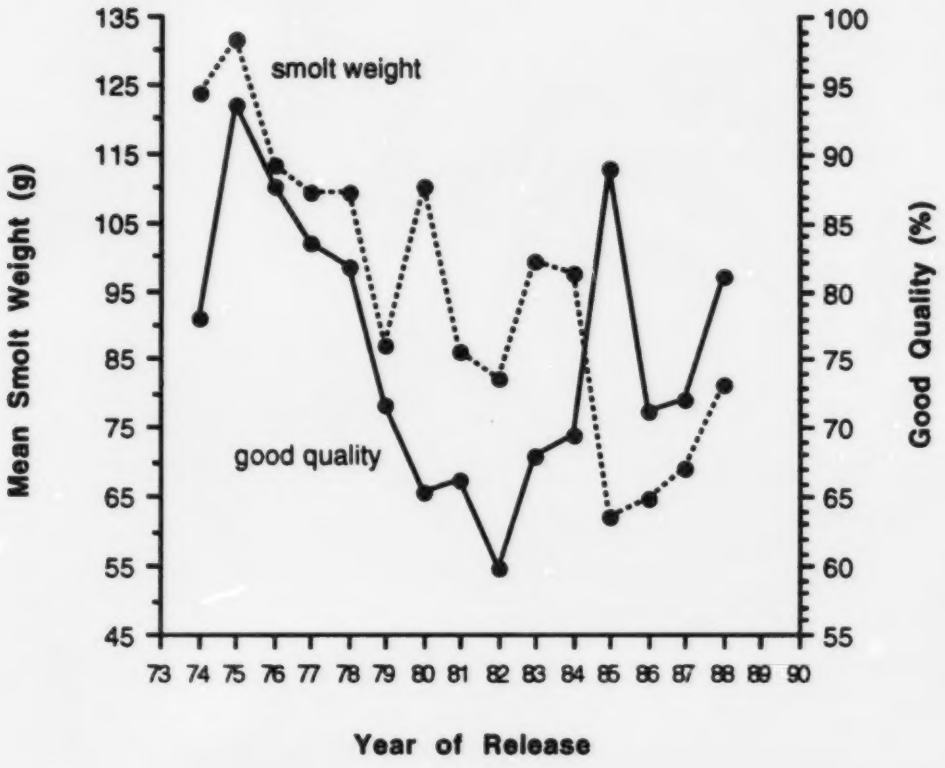

Figure 1B. Mean weight and quality of the tagged smolts released from the Mactaquac FCS to the Saint John River, N.B., during the 1974-1988 period. Weight and quality values shown for the 1974-1984 period are for 2+ smolts and those shown for the 1985-1988 period are for 1+ smolts.

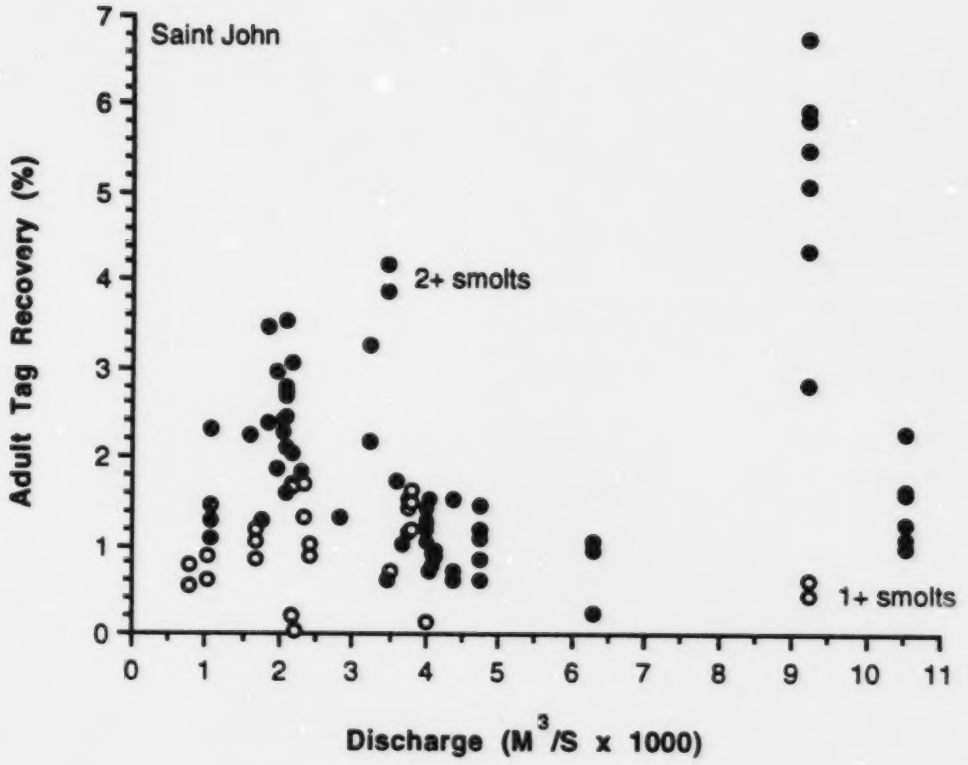

Figure 2A. The recovery (%) of tagged adult salmon resulting from the release of tagged 1+ and 2+ smolts to the Saint John River, N.B., during various levels of river discharge.

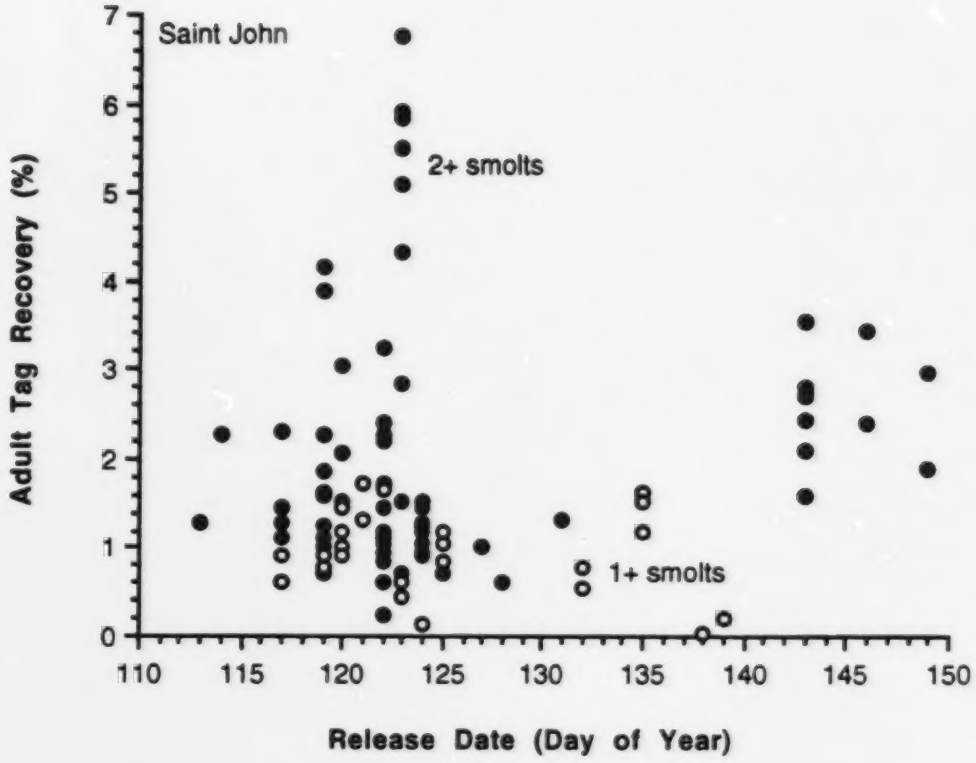

Figure 2B. The recovery (%) of tagged adult salmon resulting from the release of tagged 1+ and 2+ smolts to the Saint John River, N.B., on various dates.

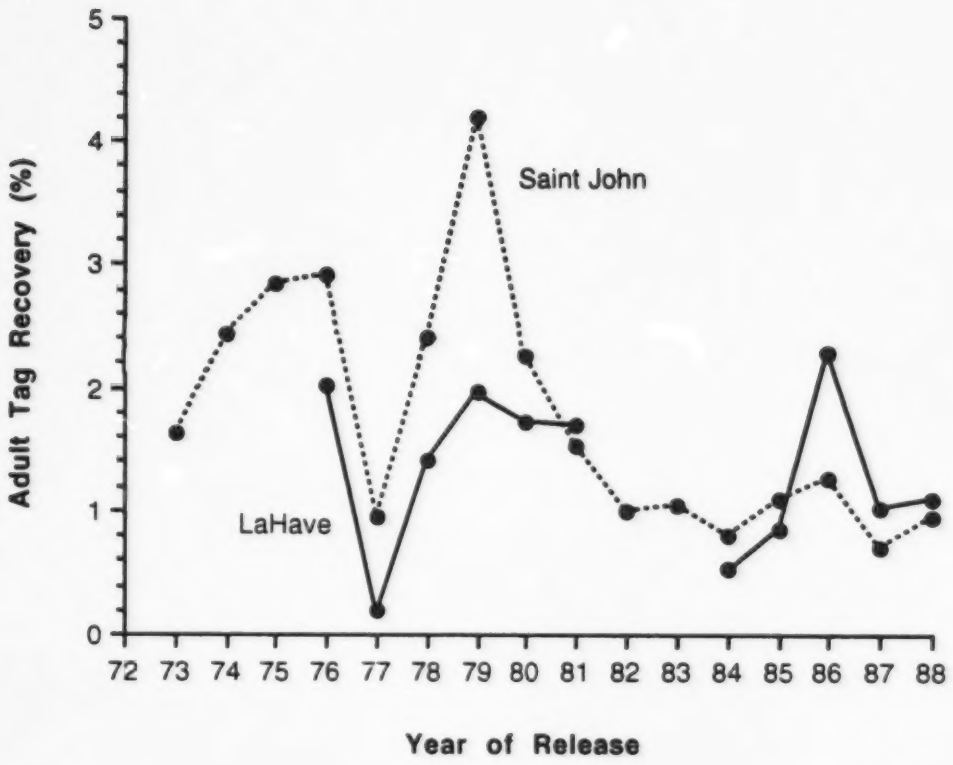

Figure 3. Mean recovery (%) of tagged adult salmon resulting from the release of groups of tagged smolts in the Saint John River, N.B., and in the LaHave River, N.S., during the 1973-1988 period.

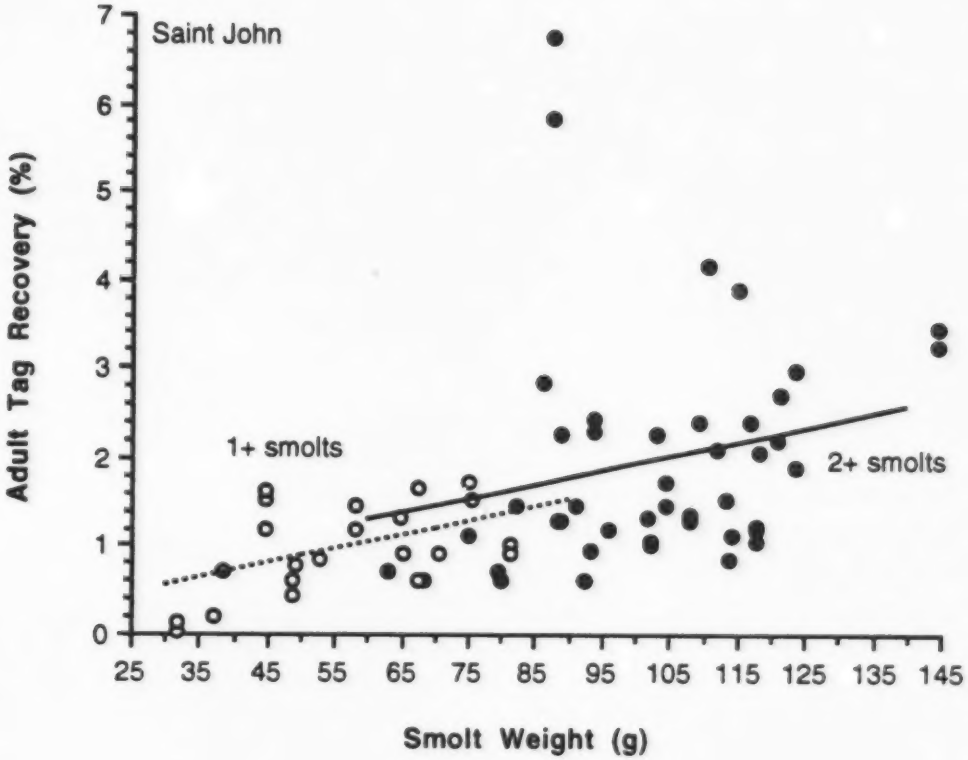

Figure 4A. The relationship between mean weight of the groups of tagged 1+ and 2+ smolts released in the Saint John River, N.B., during the 1973-1988 period and the subsequent recovery (%) of tagged adult salmon.

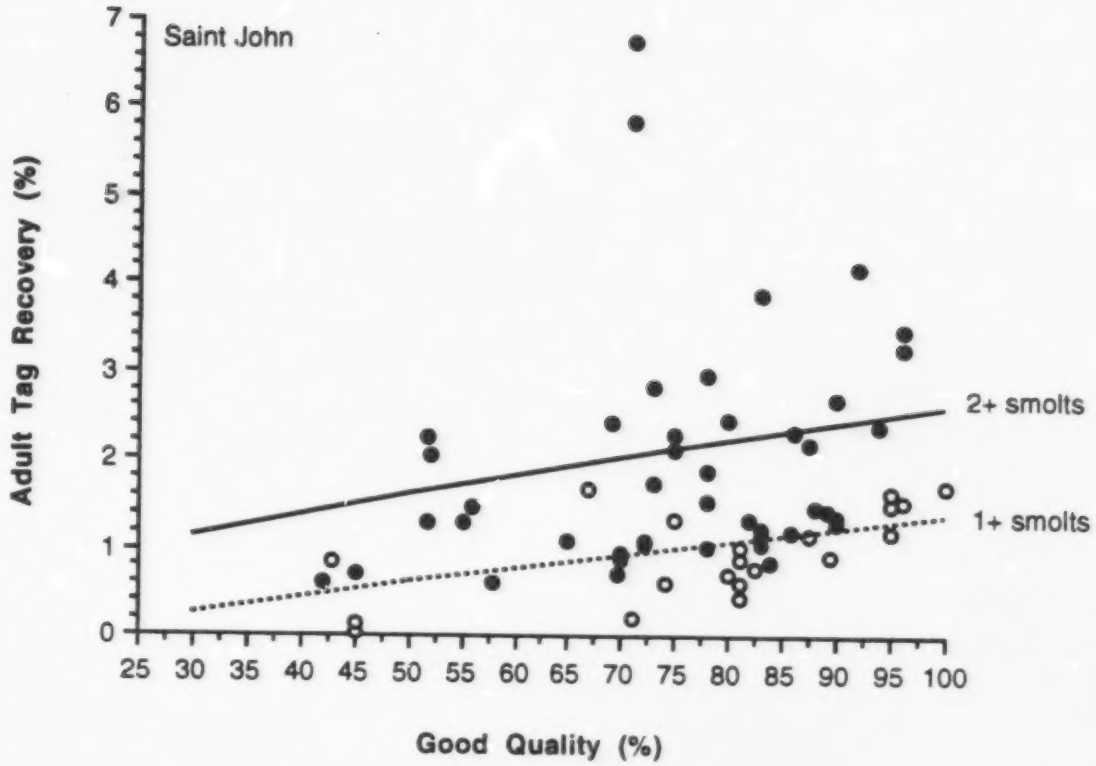

Figure 4B. The relationship between the percentage of good quality tagged 1+ and 2+ smolts released in the Saint John River, N.B., during the 1973-1988 period and the subsequent recovery (%) of tagged adult salmon.

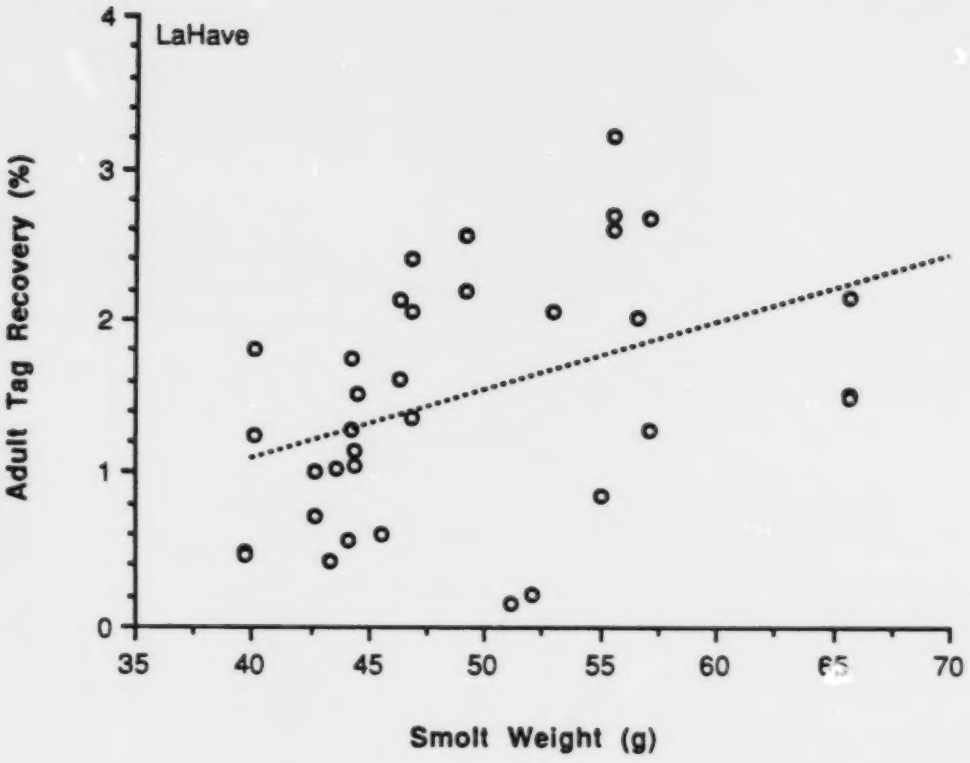

Figure 5A. The relationship between the mean weight of the groups of tagged 1+ smolts released in the LaHave River, N.S., during the 1976-1988 period and the subsequent recovery (%) of tagged adult salmon.

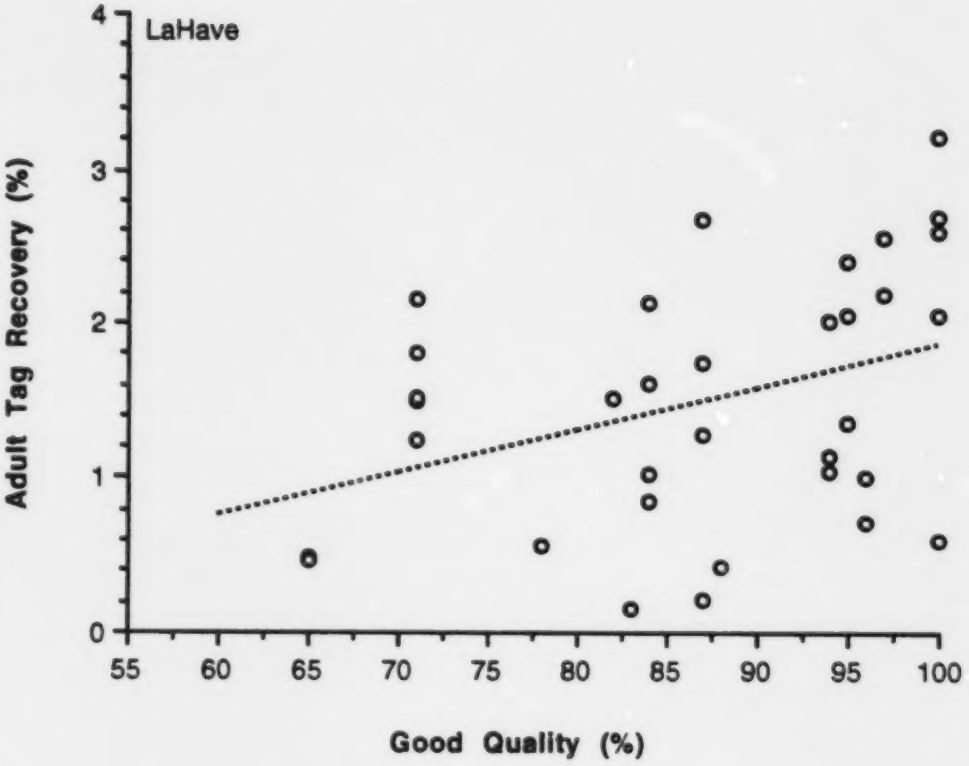

Figure 5B. The relationship between the percentage of good quality tagged 1+ smolts released in the LaHave River, N.S., during the 1976-1988 period and the subsequent recovery (%) of tagged adult salmon.